**CONTRASTING INTERPRETATIONS OF TES SPECTRA OF THE 2003 ROVER "OPPORTUNITY" LANDING SITE: HEMATITE COATINGS AND GRAY HEMATITE.** L. E. Kirkland[1,2], K. C. Herr[2], and P. M. Adams[2], [1]Lunar and Planetary Institute, kirkland@lpi.usra.edu, [2]The Aerospace Corporation, kenneth.c.herr@aero.org; paul.m.adams@aero.org. On-line information and data: www.lpi.usra.edu/science/kirkland

**Introduction:** Since 2001, there have been two, parallel interpretations of Mars Global Surveyor Thermal Emission Spectrometer (TES) observations of Sinus Meridiani. The TES team has consistently and dominantly argued that a deposit of coarse hematite is the only spectral match, and refers to the site as a "gray hematite" deposit. On the other hand, the Aerospace remote sensing team has argued that a hematite coating better matches the TES spectra, although coarse hematite is also a viable option. Coatings do not necessarily imply abundant water, while coarse hematite does. The debate illustrates two points: (1) the attention that an option receives could be perceived as proportional to the amount of water that it implies; and (2) coatings appreciably increase ambiguities in the interpretations.

*1. TES team: Coarse-only.* The TES team specifically ruled out a hematite coating as a possible match to the Sinus Meridiani spectra (Fig. 1) [1]. The TES team describes the site as a regional deposit (~750 km x 350 km) containing "gray hematite" (coarse hematite particles). They advocated the "gray hematite" deposit as strong evidence for long periods of past abundant water at that site, causing the decision to land the rover "Opportunity" there in January, 2004.

*2. Aerospace team: Hematite coatings.* In contrast, the Aerospace remote sensing team has demonstrated that (1) thin hematite coatings also match the TES observations (Fig. 2); (2) a coating can match better than coarse hematite has been demonstrated to do (Fig. 2); and (3) coatings and coarse particles also match at visible wavelengths (Fig. 3) [2,3,4]. A thin coating (~5–10 μm thick) and a low fractional exposure (<5%) could cause the observed TES signature [3]. However, the coating option has received essentially no attention, possibly because an option that may not require abundant water has less appeal, including for landing site discussions. As a result, coating formation pathways are little studied, so that a current potential irony for the Opportunity landing site would be if coatings in fact mark regions that have a particularly dry history.

*Rover observations?* The rover can potentially determine whether hematite coatings are present. It will land on Jan 24th, before the Feb abstract deadline for instrument team members, but after the LPSC Jan 13th abstract deadline for independent researchers.

If the rover finds that hematite coatings cause the TES signatures, then the "coarse-only" interpretation is incorrect. Either way, the demonstrated ambiguity shows that coatings do complicate interpretations.

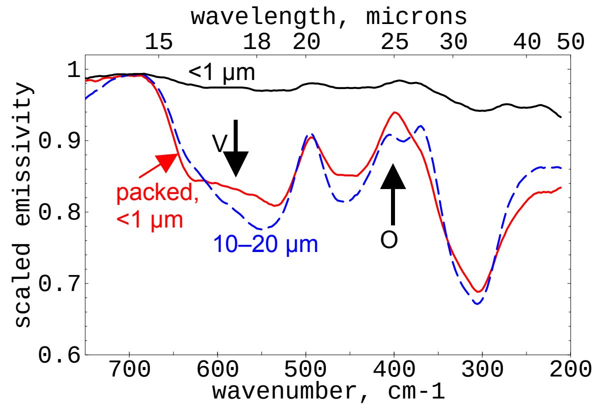


**Fig. 1: Data that led the TES team to rule out a hematite coating,** from Fig. 7 of *Christensen et al.* [1]. The labels give the sample particle sizes. The mismatch of the packed sample to the coarse hematite particles (10–20 μm) led the TES team to rule out coatings as an option. However, unlike a consolidated coating, the packed sample still exhibits volume scattering (arrow "V") because the hand packing did not sufficiently consolidate the material [3]. In addition, arrow "O" notes where the packing oriented the crystals, and further altered the spectral shape [3]. The differences show why a packed sample is an incorrect analog to a coating, and how an incorrect analog can lead an interpretation astray.

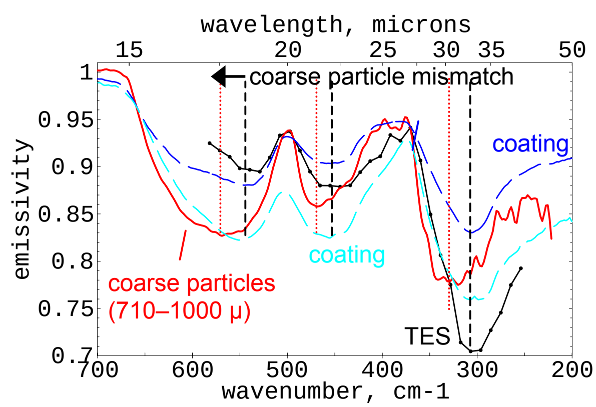


**Fig. 2. Hematite coatings match Sinus Meridiani.** The two dashed traces show hematite coating signatures. The solid trace shows coarsely particulate hematite [5]. The TES spectrum is of Sinus Meridiani, scaled to plot with a similar spectral contrast for comparison. The dashed, vertical lines illustrate the band centers of the coarse hematite (red vertical lines) and coatings and TES spectra (black vertical lines). The coatings are: blue="bhm3_blk_a"; blue-green = "bhm4_blk_b", as 1-biconical reflectance. The TES signature of Sinus Meridiani is an average of 11 TES spectra (ICK 643888002 to -024, detector 5, in apparent emissivity, with an atmospheric compensation applied [6], scaled as (3*x)-2. TES lab spectrum: "bur2600", 3-point boxcar smoothing applied to increase the signal-to-noise ratio.

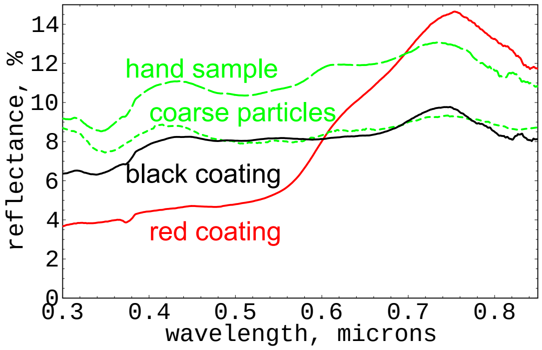


**Fig. 3: Hematite coatings and coarse hematite are essentially indistinguishable at visible wavelengths.** These spectra are of a hand sample (sample "gry_hem"), and a black ("bhm3") and a red hematite coating ("bhm1"), measured at The Aerospace Corporation. Coarse particles are 150–250 µm from [7], "gds_69_a150-250u". Sample "bhm3" is from near Bunker Hill Mine, Inyo Mountains, California.

**Previous work.** TES spectra of Sinus Meridiani exhibit bands near 18, 23, and 33 µm that are broadly consistent with hematite [1,8] (Fig. 2). The clear spectral band contrast indicates that *unconsolidated*, small hematite particles do not cause the signature.

Optically smooth surfaces (including coatings) can exhibit conspicuously strong spectral signatures that make them stand out even at low abundance (Fig. 4) [3,4]. For example, a sample with a smooth hematite coating exhibited a 23 µm hematite band depth of ~45%. TES Sinus Meridiani spectra exhibit a 23 µm band depth of ~2%, giving an aerial exposure of ~4% for this case. In contrast, optically rough surfaces have a "stealthy" signature (low band contrast, Fig. 4) that can make a material remain undetected [4,6,9].

**Discussion.** The Aerospace remote sensing team has reiterated since 2001 that hematite coatings match the TES data, and can match better than coarse hematite has been demonstrated to do [e.g., 2,3,4]. Thus spectrally, it is more probable that the Sinus Meridiani hematite is a coating. However, the spectral differences are slight enough (Fig. 2) that we consider either a possibility.

Nonetheless, the "coarse-only" interpretation has dominated because an interpretation that points to water can be perceived as having greater rewards in arenas critical to researchers, including publications and funding. On the other hand, if coatings indicated abundant water, then that would likely have encouraged broad presentation of the coating option. Infrared remote sensing interpretations can be particularly susceptible to such "follow the water" influence because spectral signatures can be non-unique. However, particularly for landing site selection, it is critical that all viable options are thoroughly and openly presented to the community.

Coatings studies are important to Mars research because: (1) Both visible and infrared identification of coatings vs. coarse samples remains somewhat ambiguous. (2) Coatings are an important possibility for Mars, particularly for astrobiology studies. (3) A hematite coating may not require abundant water to form, which impacts geologic and climatic interpretations. For example, a current potential irony for the Opportunity site would be if coatings denote a consistently dry site. (4) A hematite coating may explain non-detection of coexisting aqueous alteration minerals, and the lack of hematite wind streaks. (5) Roughness impacts band strength (Fig. 4), so that current "hematite abundance maps" may map the surface texture rather than abundance [4,6,9]. (6) The atypical optical properties of coatings can impact measurements by orbited and rover instruments.

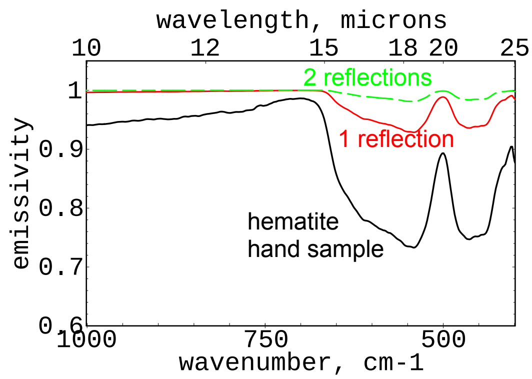


**Fig. 4: Smooth surfaces have higher spectral contrast.** Surface roughness causes multiple reflections that reduce the spectral contrast [4,6,9]. The lower trace shows the spectrum measured of a hematite hand sample (sample "grhemfrhr"). The middle and upper traces simulate one and two surface reflections, respectively, as may result from surface roughness. The trend illustrates why good spectral contrast indicates the presence of some optically smooth surfaces. The spectrum was measured in hemispherical reflectance and converted to emissivity as one minus reflectance.

**References:** [1] Christensen P.R. et al. (2000) *JGR, 105*, 9632. [2] Kirkland L.E. et al. (2001), *Eos Trans. AGU*, 82(20). [3] Kirkland, L.E. et al. (2003) Hematite coatings match TES spectra of Sinus Meridiani, Mars, *LPSC XXXIV*, abs. 1944. [4] Kirkland L.E. et al. (2003), Infrared stealthy surfaces: Why TES and THEMIS may miss substantial mineral deposits on Mars, *JGR*, 10.1029/2003JE002105, 108(E12), preprint www.lpi.usra.edu/science/kirkland. [5] Christensen, P.R. et al. (2000) *JGR, 105*, 9735. [6] Kirkland L.E. et al. (2002), First Use of an Airborne Thermal Infrared Hyperspectral Scanner for Compositional Mapping, *Rem. Sens. Env. 80*, 447. [7] Clark R. et al. (1993) *USGS Open File Rep. 93-592*. [8] Estep-Barnes P.A. (1977), ch.11, *Physical Methods in Determinative Mineralogy*, ed. J. Zussman. [9] Kirkland L.E. et al. (2001) *Appl. Optics 40*, 4852.

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